Earthquake Engineering Research

- Applied Research and Development
- Addressing Gaps in State-of-the-Practice
- Transfer State-of-Art to State-of the-Practice

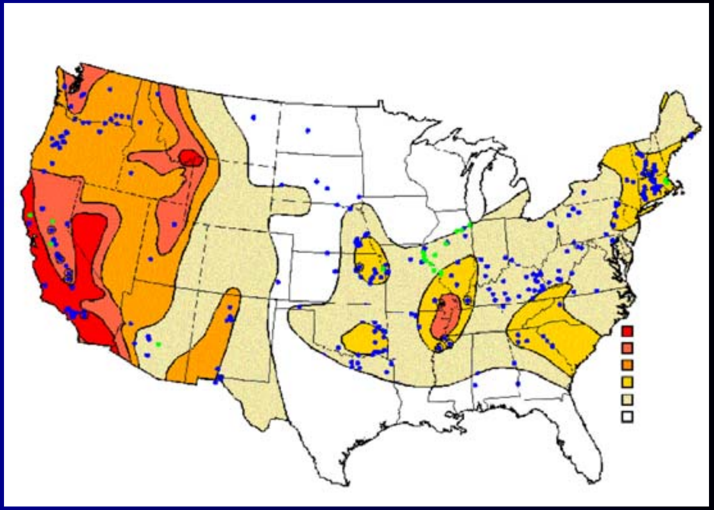
ERDC

Engineer Research and Development Center

Earthquake Engineering Research

Problem

- Corps has 200 dams and 73 intake towers in areas with significant seismic hazards
- Most dams were constructed when earthquake engineering was in its infancy
- Using current technology, most of these would be judged seismically inadequate
- Remediation costs of these structures could reach $20 billion



Seismic zone map showing SMIP project sites

Earthquake Engineering Research

Purpose

- To improve our ability to predict the performance of a dam under seismic loads, and to improve our ability to design and construct cost-effective remediation

Mormon Island Dam, CA remediation

Major Thrusts

- Engineering geology / seismology
- Geotechnical earthquake engineering
- Structural earthquake engineering

Target Structures

- Embankment dams
- Concrete dams
- Intake tower / outlet works

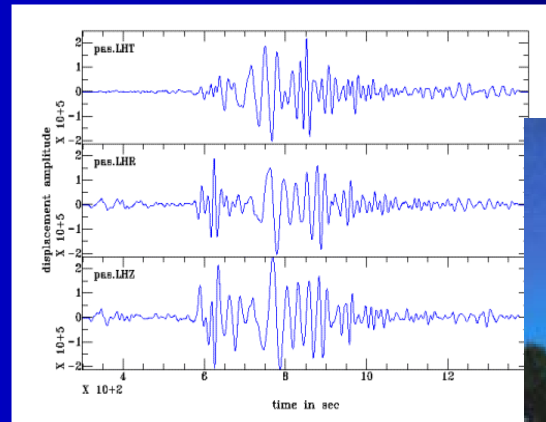
Sardis Dam, MS remediation

Interagency Coordination

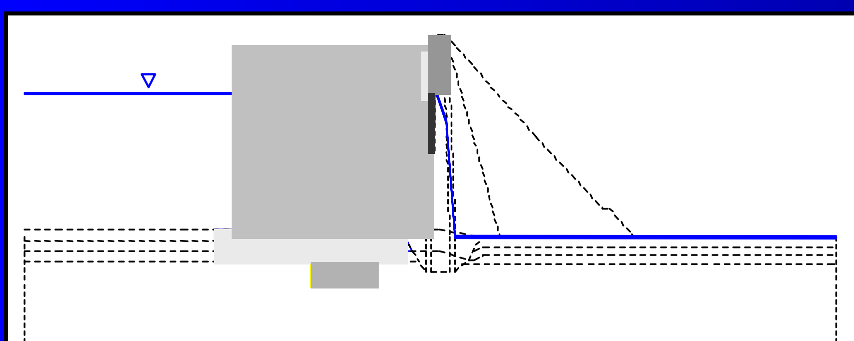
- National Earthquake Hazard Reduction Program, focused on buildings and lifelines, BSSC, FEMA, USGS, NIST, NSF - MCEER , PEER, MAEC and Universities
- FHWA Highway Seismic Research Programs (MCEER)
- Leveraging with NSF, Corps Districts, US Bureau of Reclamation, BC Hydro
- UJNR US-Japan Panel on Wind and Seismic Effects, EPRI, CALTRANS, NSTC, SNDR

Earthquake Engineering Research

Earthquake
Ground Motions



Site Characterization



Performance Assessment Using
Numerical and Physical Models

Remediation

Research Strategy: **Embankment Dams**

Ground Motions

Geology / Seismology

Design EQ Ground Motion Analysis System

Site Characterization

Shear Wave Velocity Database
Geophysical Methods
Penetration Testing

Performance Assessment

Newmark Analyses

Behavior of Liquefying Soils -
Failure Mechanisms & Damage Assessment -

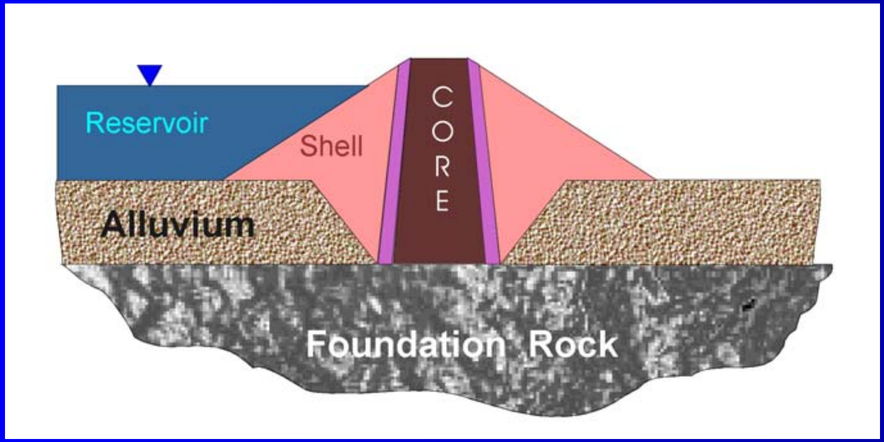
Primary Analysis Tool

Large Deformation Analysis of Embankment

Assessment & Remediation

Phase II

Seismic Evaluation and Rehabilitation Program



Research Strategy: **Concrete Dams & Outlet Works**

Ground Motions

Intake Towers
Outlet Works

Quantify Ductility

Primary Analysis Tool

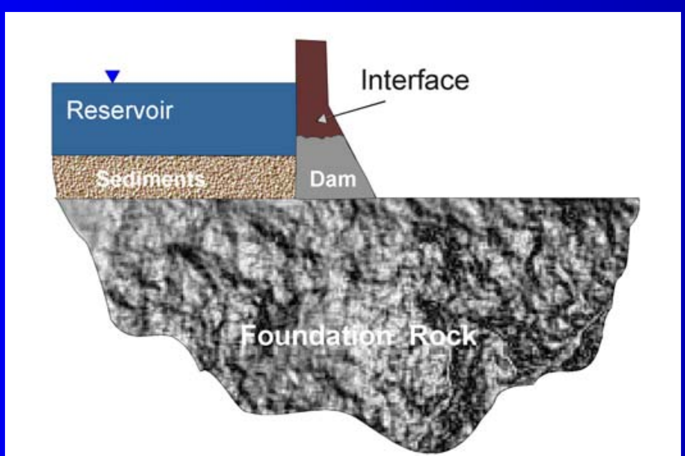
Time - History
Non - Linear Analysis

Subbottom Absorption

Conventional Concrete Dams

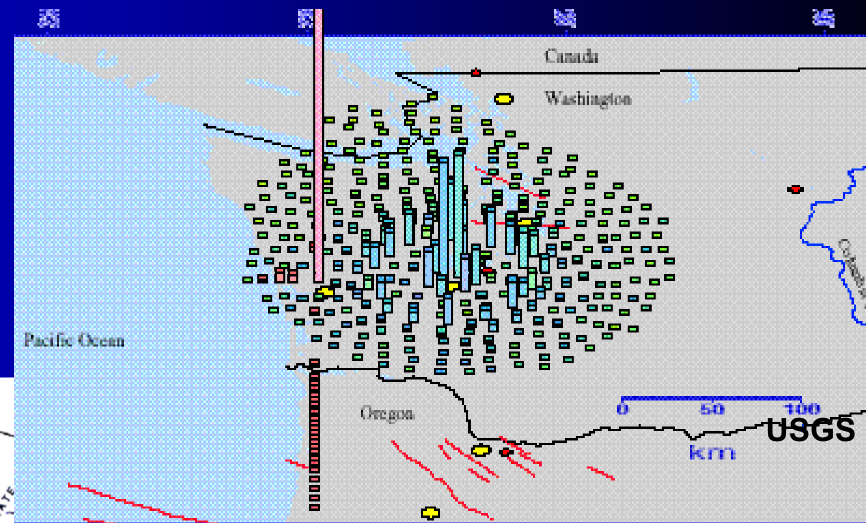
Roller Compacted Concrete

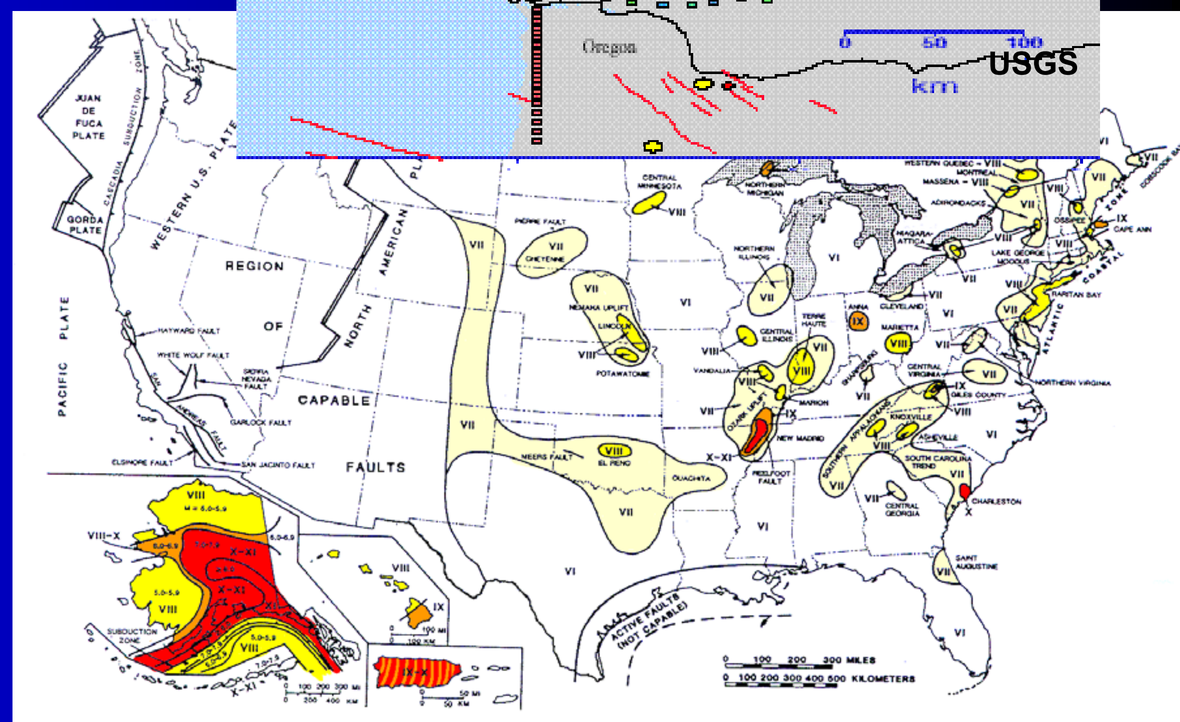
Moment / Shear / Thrust
Post - Processors



Research Strategy: Geological-Seismological Investigations

- Continuing transition of geologic & seismologic research to engineering-relevant data
- Incorporated latest knowledge into methods for geological-seismological evaluations of earthquake hazards enabling accurate site-specific ground motions for Corps projects



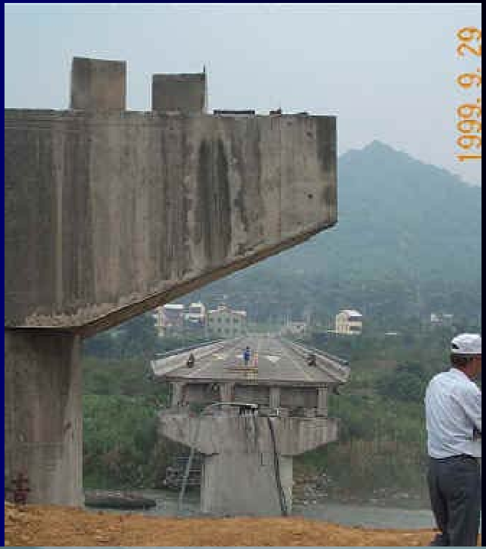


Seismic source zones for U.S.

Earthquake Reconnaissance - Turkey & Taiwan

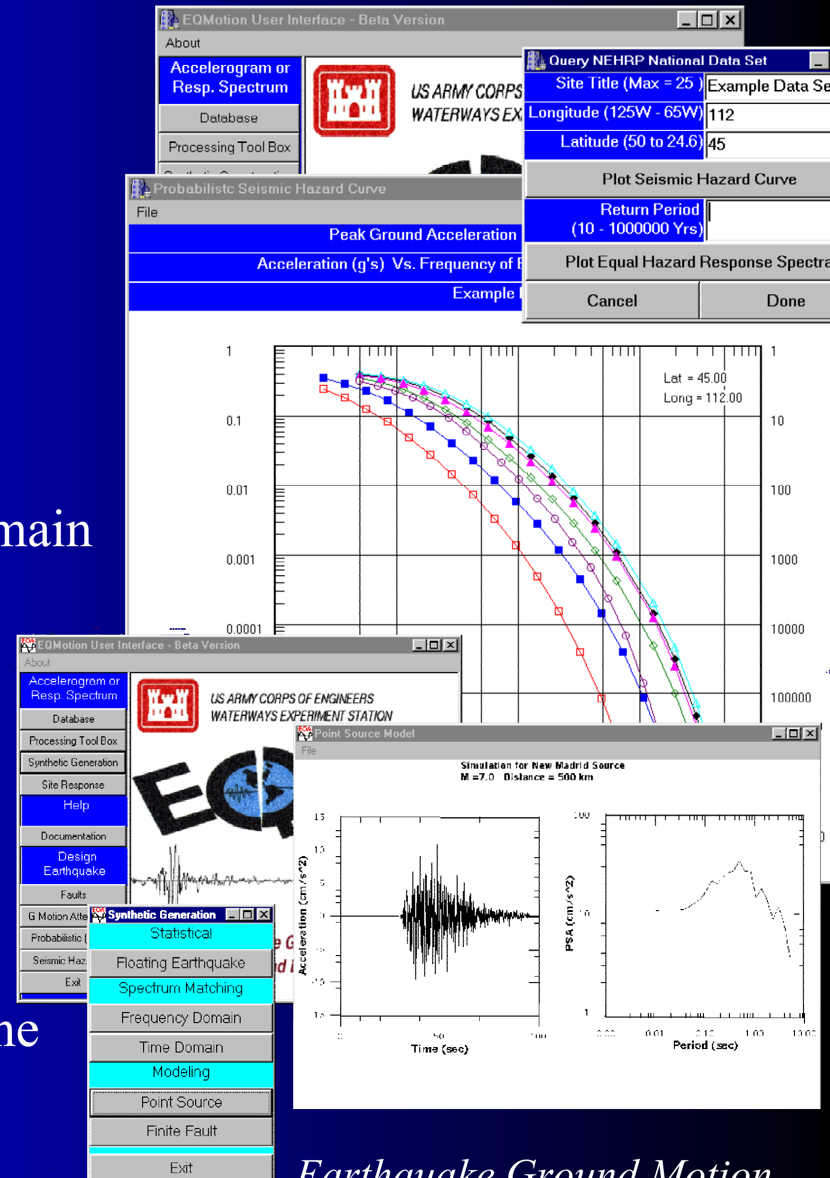
- **Turkey**
  - **Observed silt liquefaction**
  - **Observed delayed settlement**
- **Taiwan**
  - **Best data**
  - **Large event**
  - **Ground Motions**
  - **Full-scale test**
  - **Dam Performance**
  - **Hydrodynamics**

Taiwan Earthquake Photos



Design Earthquake Ground Motion Analysis System (DEQAS)

- Modular, Windows-based tool box
- Site-specific seismic hazard assessment
- USGS NEHRP map data incorporated
- Corps Guidance on-line
- Modify spectra, records,frequency, time domain
- Large suite of accelerograms on line
- Large suite of attenuation functions on line
- User-interactive graphics
- Site response module (SHAKE)
- PSHA module
- Deaggregated data for cities and dams on line



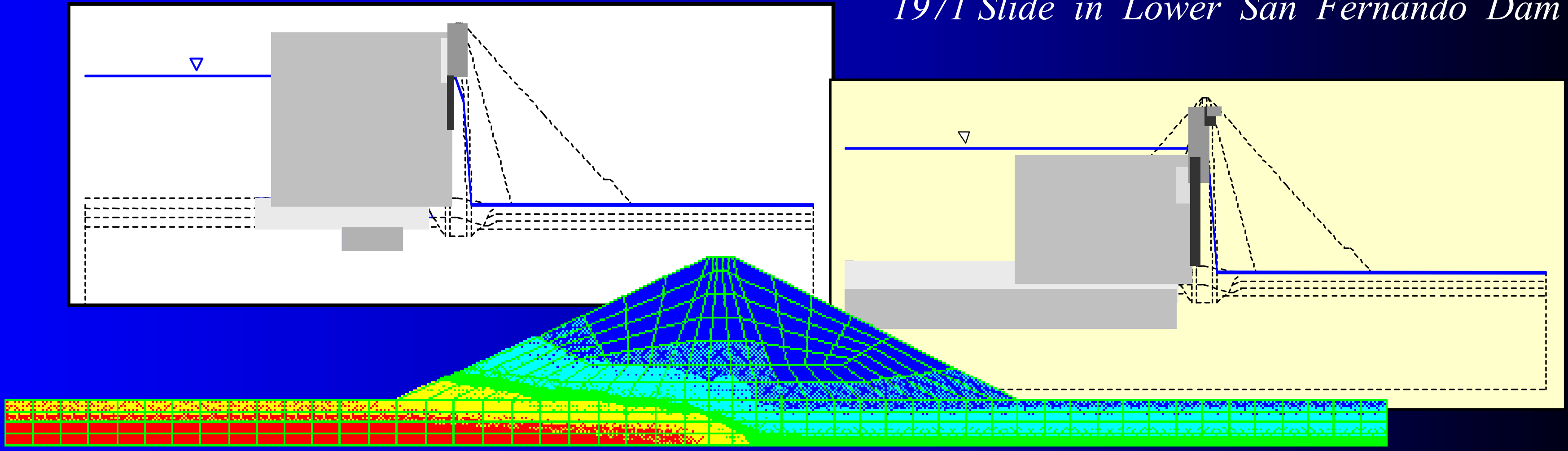
Earthquake Ground Motion Analysis and Design System

Earthquake Engineering Research
Embankment Dams

Research Thrust Areas

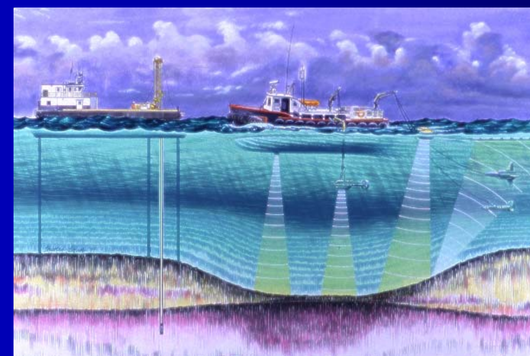
- Site Characterization
- Liquefaction
- Large Deformation Analysis

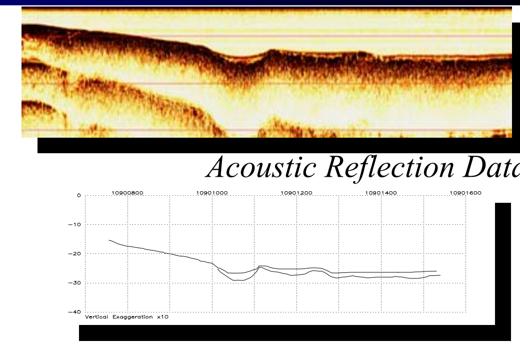
1971 Slide in Lower San Fernando Dam



Geophysical Methods for Site Characterization and Measurement of Material Properties: Waterborne Geophysics

- Subsurface stratigraphy
  - Material type
  - Distribution
  - Volume
  - Total density
  - Stiffness, elastic properties
  - Void Ratio
- High-resolution side-scan image mosaics
  - Pre- and post- earthquake conditions, underwater





Acoustic Reflection Data

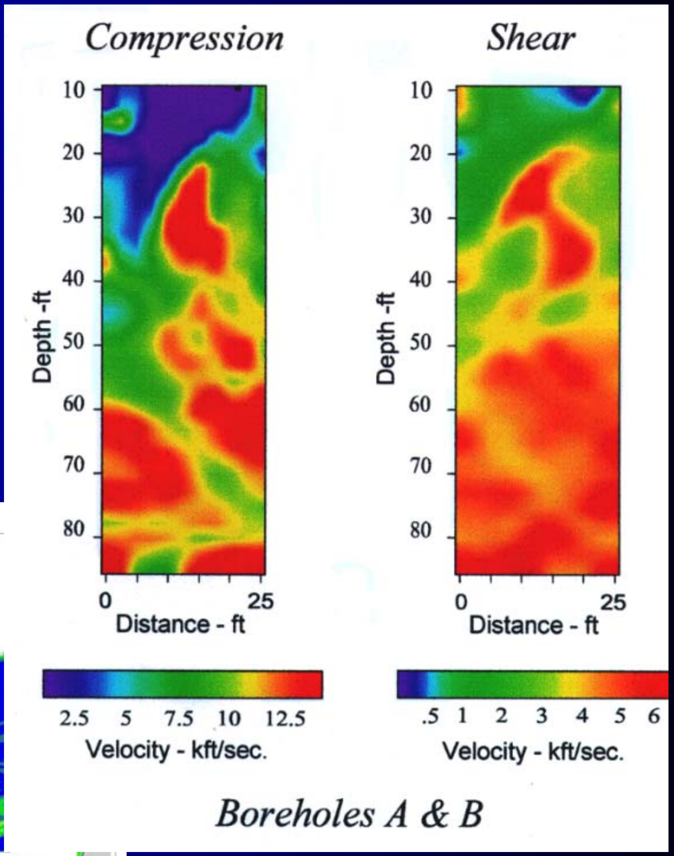
Interpreted Sediment Profile

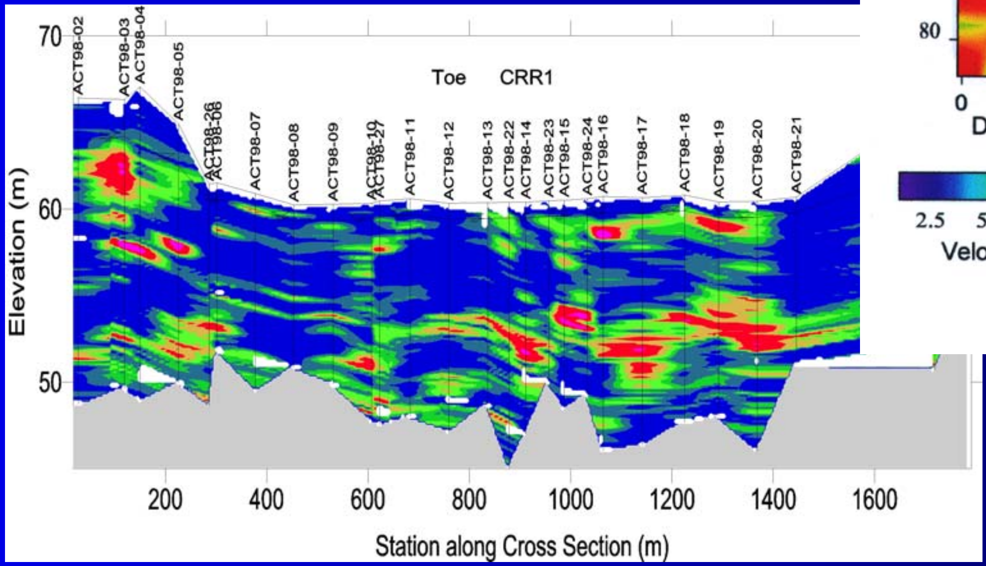
Subbottom Profiling System

Side scan sonar,
Arkabutla control structure

Geophysical Methods for Site Characterization and Measurement of Material Properties: Land-based Geophysics

- High-resolution tomography
- 3-D stratigraphy
- Engineering properties
- Liquefaction properties

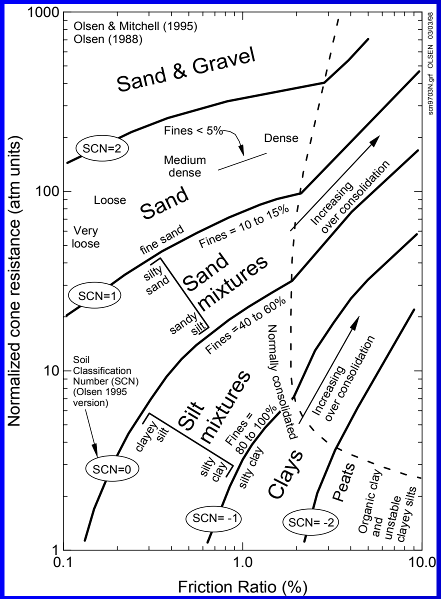




Success Dam, CA borehole tomography

Site Characterization: Penetration Testing

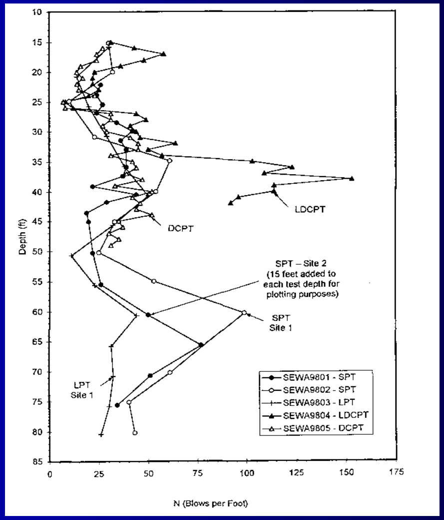
- BPT, LPT, SPT, Chamber Tests
- CPT- Olsen, Material type, peak strength, residual strength, CRR1, N_1 (60)



CPT soil behavior chart

Large-scale laboratory in situ penetration testing chamber

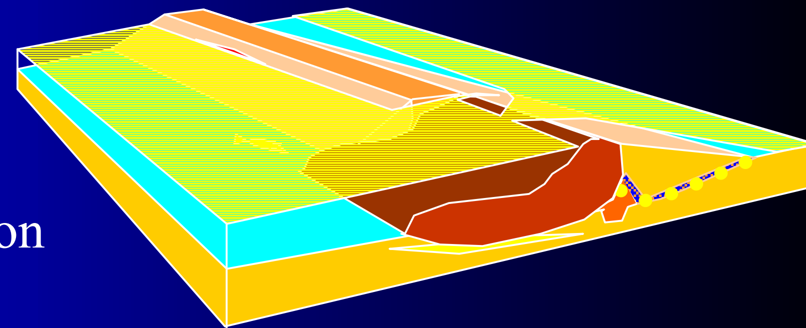
BPT Drill Rig



Comparison of Penetration Tests

Earthquake Engineering Research

- **Shear Wave Velocity Database**
  - Developed to support screening analysis, on web and DEQAS
- **Newmark Sliding Block Analysis**
  - Validated by compilation and investigation of >300 case histories, >130 dams
- **Criteria for identifying liquefiable fine-grained soils -** liquid limit off 3%



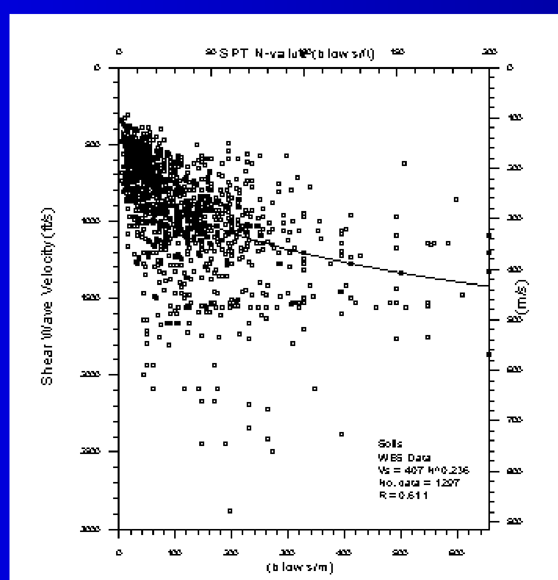


Table : C:\wanda\vsplots\WESP.DBF

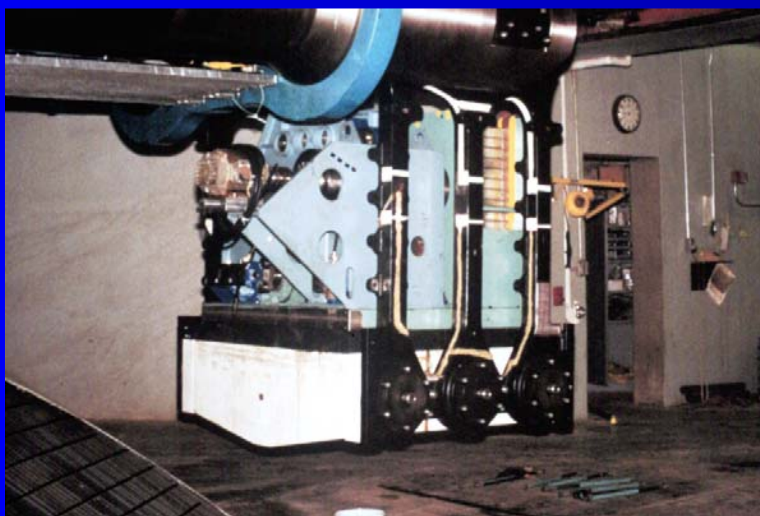
	DEPTH	DWT	SWV	PWV	N	N1	N60	N160	MATL	GO	GA	Z	GR	LL	PI	DATA
1	11.00	44.00	995	-1	11	13	11	13	SPSM	A_	QP	1	-1	-1	-1	WES
2	12.50	44.00	1005	-1	37	42	37	42	SPSM	A_	QP	1	-1	-1	-1	WES
3	14.00	44.00	1015	-1	89	95	89	95	SPSM	A_	QP	1	-1	-1	-1	WES
4	23.00	44.00	1075	-1	63	54	63	54	SPSM	A_	QP	1	-1	-1	-1	WES
5	26.50	44.00	1090	-1	69	56	69	56	SPSM	A_	QP	1	-1	-1	-1	WES
6	51.00	44.00	1125	-1	45	28	45	28	SCSM	A_	QP	1	-1	-1	-1	WES
7	5.50	55.00	705	-1	22	35	22	35	SM	FC	R	4	-1	-1	-1	WES
8	11.50	55.00	735	-1	18	21	18	21	SM	FC	R	4	-1	-1	-1	WES
9	16.00	55.00	765	-1	20	20	20	20	SM	FC	R	4	-1	-1	-1	WES
10	20.50	55.00	840	-1	22	20	22	20	SM	FC	R	4	-1	-1	-1	WES
11	25.00	55.00	995	-1	18	15	18	15	SM	FC	R	4	-1	-1	-1	WES
12	31.00	55.00	1030	-1	23	17	23	17	SM	FC	R	4	-1	-1	-1	WES
13	35.50	55.00	1025	-1	39	28	39	28	SM	FC	R	4	-1	-1	-1	WES
14	40.00	55.00	1025	-1	41	28	41	28	SM	FC	R	4	-1	-1	-1	WES
15	46.00	55.00	1025	-1	25	16	25	16	SC	FC	R	4	-1	-1	-1	WES
16	50.50	55.00	1020	-1	22	13	22	13	SC	FC	R	4	-1	-1	-1	WES
17	55.00	55.00	990	-1	8	4	8	4	SC	A_	QH	4	-1	-1	-1	WES
18	61.00	55.00	915	-1	43	24	43	24	SPSM	A_	QH	4	-1	-1	-1	WES
19	65.50	55.00	1020	-1	69	37	69	37	SWSM	A_	QH	4	-1	-1	-1	WES
20	71.50	55.00	1055	-1	83	44	83	44	ML	A_	QH	4	-1	-1	-1	WES
21	76.00	55.00	1065	-1	120	62	120	62	SM	A_	QH	4	-1	-1	-1	WES
22	80.50	55.00	1080	-1	120	61	120	61	SM	A_	QH	4	-1	-1	-1	WES
23	12.50	44.00	580	1520	9	10	9	10	CH	A_	QH	4	-1	-1	-1	WES
24	13.50	44.00	590	1510	8	9	8	9	CH	A_	QH	4	-1	-1	-1	WES
25	20.50	44.00	650	1280	10	9	10	9	CH	A_	QH	4	-1	-1	-1	WES
26	26.00	44.00	990	1725	41	34	41	34	CH	A_	QH	4	-1	-1	-1	WES
27	32.00	44.00	990	2475	31	24	31	24	ML	A_	QH	4	-1	-1	-1	WES
28	39.00	44.00	940	4560	38	27	38	27	SPSM	A_	QH	4	-1	-1	-1	WES
29	6.00	125.00	810	2560	27	41	27	41	CL	FC	R	2	-1	-1	-1	WES

Table : C:\wanda\vsplo...

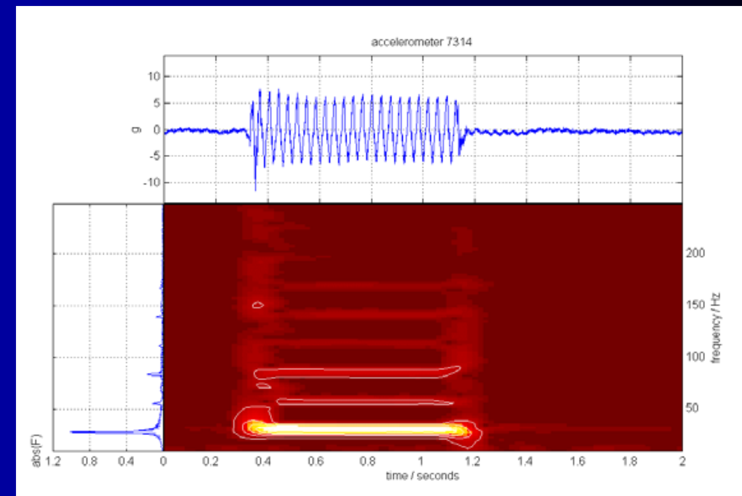
Record 1 View

Earthquake Engineering Research: Centrifuge Modeling

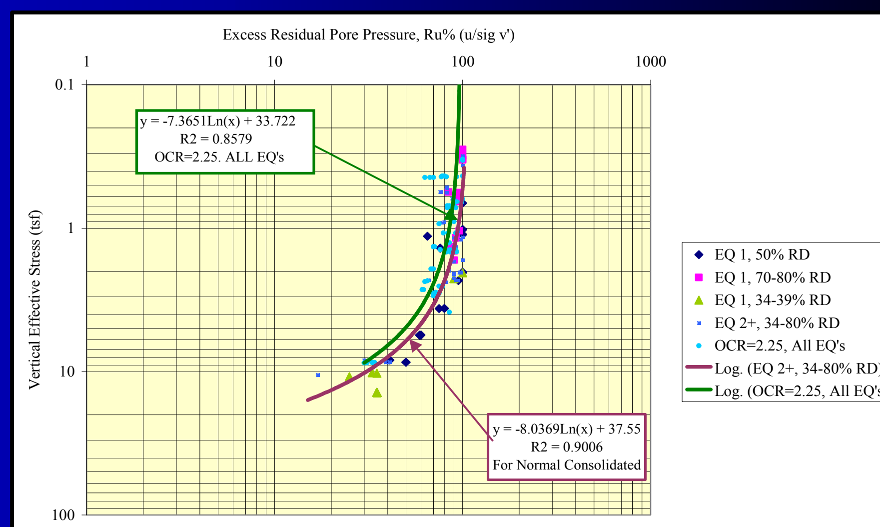
- **Research into the behavior of liquefying soils**



Earthquake shaker mounted on centrifuge arm



Wavelet analysis of soil response to earthquake loading response



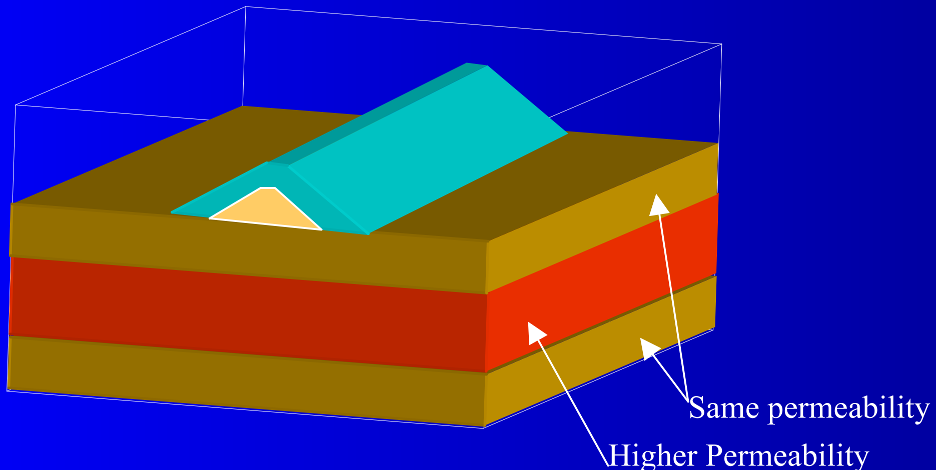
Dynamic Induced Residual Excess Pore Pressure Limit

Earthquake Engineering Research

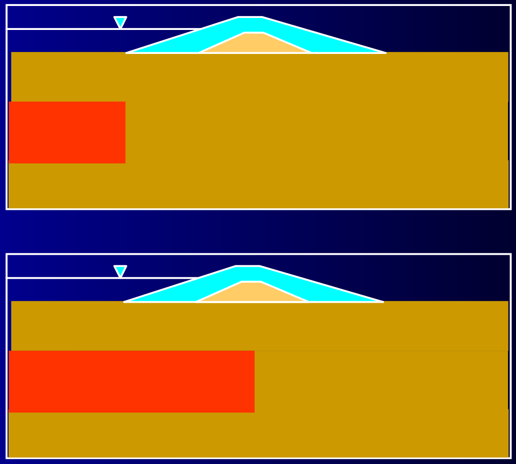
- **Failure Mechanisms and Damage:** Improve state-of-the-practice for determining performance of dams in response to liquefaction of soils

Slide in Lower San Fernando Dam - 1971

Centrifuge (physical) modeling



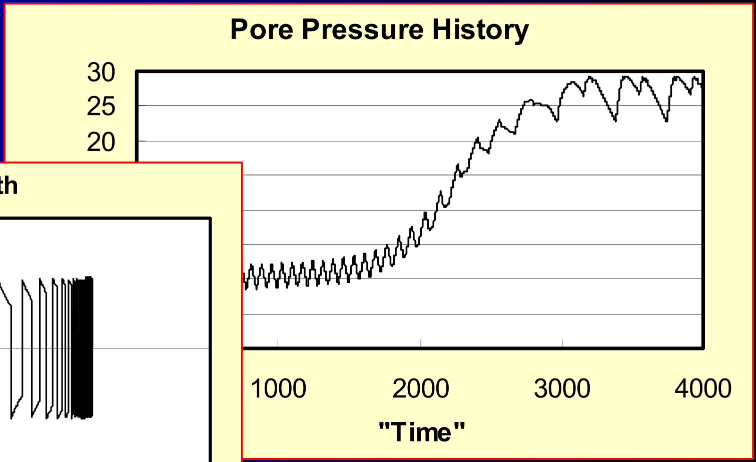
Effect of layer permeability

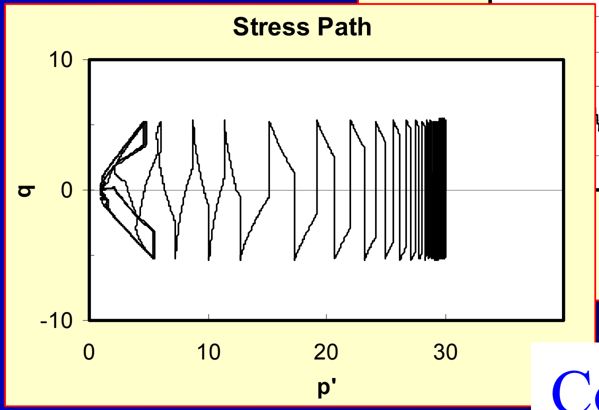


Extent of liquefiable layer

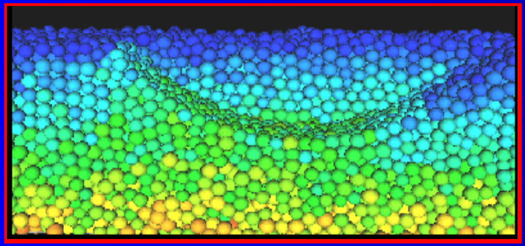
Earthquake Engineering Research

- **Seismic Stability and Deformations of Earth Structures and Foundations**
  - Use of numerical modeling to improve estimation of post-earthquake deformation
  - Fully coupled model, pore pressure generation with stress

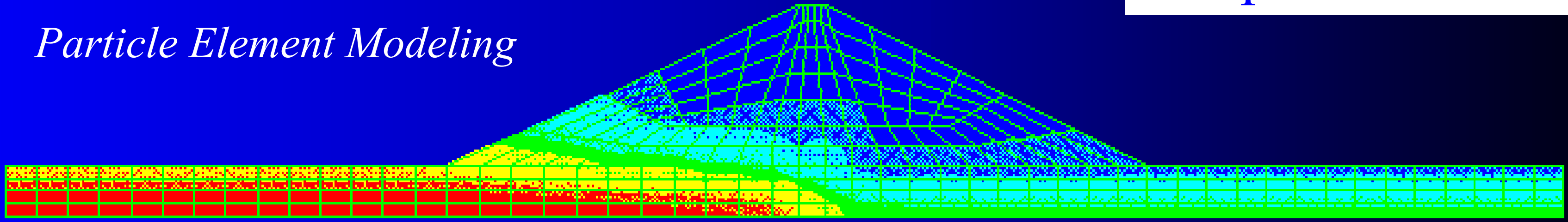




Coupled with Stress



Particle Element Modeling



Idealized dam initial pore water pressure